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VIBRATION PREDICTION AND OPTIMIZATION: THE CASE HISTORIES OF QUARRY BLASTS IN THAILAND

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ABSTRACT

Vibration measurements for 3 types of quarry rock at a number of sites in Thailand have been carried out and analyzed. The dominant vibration parameters in bench blasting are based on the peak particle velocity and the blast frequency. These readings are evaluated using the threshold limit of damage and the probability method. Results indicate that the damage possibility is low and within the acceptable limit. A further step of evaluation is to predict the safe distance from vibration by utilizing the modified trend line. This paper also describes steps taken in the planning stage to determine the optimal design model for a particular quarry area.

INTRODUCTION

Quarry blasts for construction materials in Thailand have been operated in several rock types. Most of them is in Permian limestone. Others rocks are Cretaceous granite and Tertiary basalt. The quarries that have been investigated are located in various regions. Major quarries are in the northeast side of Bangkok, approximately 100 km.

The size of quarry is defined as the large size when its production exceeds a limit of 200,000 cubic meters per month, otherwise it is classified as the small size. All quarries of large sizes are limestone quarries in which they belong to Portland cement companies.

Fig. 1. The digital recordings for vibration data and air blast intensity at the quarry site.

VIBRATION ASSESSMENT AND PREDICTION

Assessing the stability of bench and selecting an appropriate drill pattern are the prerequisite of the quarry blasts [Tangchawal et al., 1999; Tangchawal, 2000 a]. During bench blasting, vibration measurements and associated impacts at selected sites (Figure 1) for both large and small quarries are carried out. Field recordings of significant impact parameters are the peak particle velocity and the dominant frequency. They are tabulated and statistically compared. The occurrence of cracks within the residence structure near the blast site is concurrently investigated and recorded.

Initial vibration evaluation

For an initial assessment of ground vibration, our research team evaluates the vibration data by using the method of threshold limit line on the damage possibility suggested by the U.S. Bureau of Mines [Siskind, et al., 1980]. There is a statement of confirmation that the blasting practice in Thailand, either on a large-size quarry or on a small-size quarry, has taken at a low risk of damage. The graphical plots shown in Figures 2 and 3 indicate many vibration recordings from these shots are below the U.S. threshold limit line.

Method of probability evaluation

The probability method is applied to field data of the peak particle velocity and the dominant frequency assumed having the normal distribution and log-normal distribution. Their probabilistic results of the minimum particle velocity obtained from 3 rock types, as shown in Table 1, indicate the safe and efficient blast operations. These analyzed results show that the minimum particle velocity would occur outside the 95% confidence limit of the 3 rock types, is less than 0.007 m/s. The damage risk at any frequency from the control blasting is slightly low and acceptable.

Another method of vibration prediction

One solution to predict the vibration impact, the author plots the peak particle velocity as a function of the scaled distance. The concept is based on the square root scaling method where $R/W^{1/2}$ is compared versus the peak particle velocity (V). The parameter R is the distance between vibration transducer and blast face, and W is the largest explosive weight per delay. Since these plots are classified based on the quarry sizes and rock types, their relationships seem to be highly scatter and the majority of correlation values is below 0.5 (Table 2). These correlation coefficients indicate the locations of quarry may also have affected in some ways.

Fig. 2. Vibration recordings from various large limestone quarries compared with the U.S. threshold limit line.

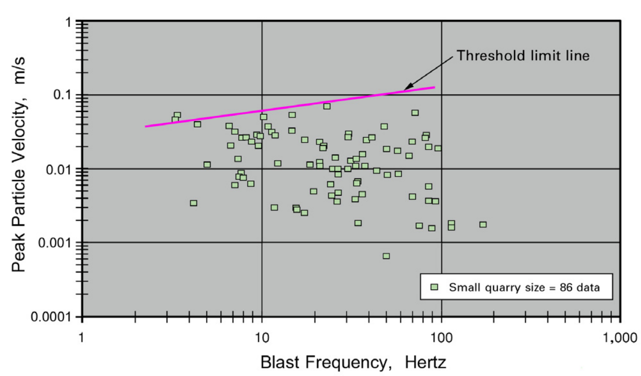

Fig. 3. Vibration recordings from various small quarries compared with the U.S. threshold limit line.

Table 1. Results of the minimum particle velocity at the lower bound of 95% confidence limit obtained from the probability analysis [Tangchawal et al., 1999; Tangchawal 2000 a].

Frequency Type	Quarry Notation	Minimum Particle Velocity (x 10^{-3} m/s)	
		Normal Mode	Log-normal Mode
All frequency	LL	1.64	4.74
	SL	2.83	4.38
	SG	1.85	1.53
	SB	1.63	1.00
High frequency (≥ 40 Hertz)	LL	0.60	0.31
	SL	2.32	0.94
	SG	6.44	1.59
	SB	0.76	0.23
Low frequency (< 4 Hertz)	LL	1.63	3.55
	SL	N/A	N/A
	SG	N/A	N/A
	SB	N/A	N/A

Notes: 1. Quarry characters are:
LL = large-size limestone quarries
SL = small-size limestone quarries
SG = small-size granite quarries
SB = small-size basalt quarries.
2. The N/A character means the results are not available. There are not enough field data to be analyzed in the probability method.
3. Values of peak particle velocity causing threshold damage for modern residence structures are 0.019 m/s at low frequency level, and 0.050 m/s at high frequency level [Siskind et al., 1980].

Table 2. Regression equations and their correlation values at 50% confidence limit analyzed from different quarries of 3 rock types [Tangchawal et al., 1999; Tangchawal 2000 a].

Size of Quarry and In-situ Rock	Number of Field Data	Original Trend Line	
		Regression Equation	Coefficient Value
Large limestone quarries	111	$V = 0.9565\left(\frac{r}{W^{1/2}}\right)^{-1.8479}$ m/s	0.553
Small limestone quarries	86	$V = 0.0904\left(\frac{r}{W^{1/2}}\right)^{-1.0895}$ m/s	0.284
Small granite quarries	27	$V = 0.1267\left(\frac{r}{W^{1/2}}\right)^{-1.2102}$ m/s	0.445
Small basalt quarries	40	$V = 0.1043\left(\frac{r}{W^{1/2}}\right)^{-1.1594}$ m/s	0.332

Table 3. The design chart for explosive weights (kg) per delay of the quarry 1 as determined using Figure 4.

Distance, m	Quarry 1, kg	Quarry 2, kg	Quarry 3, kg	Quarry 4, kg	Quarry 5, kg	Quarry 6, kg	Quarry 7, kg
150	117.41	64.31	66.98	130.64	160.85	75.71	133.73
175	159.81	87.53	91.16	177.82	218.93	103.05	182.02
200	208.73	114.32	119.07	232.25	285.95	134.59	237.74
225	264.18	144.69	150.70	293.95	361.91	170.34	300.89
250	326.14	178.63	186.05	362.90	446.80	210.30	371.47
275	394.63	216.14	225.12	439.10	540.63	254.47	449.47
300	469.65	257.23	267.91	522.57	643.40	302.83	534.91

Notes:
1. The permitted peak particle velocity is 0.025 m/s.
2. Quarry characters in this Table and Figure 4 are:
   quarry 1 = Nakorn Luang Cement, Saraburi, Thailand
   quarry 2 = Siam Cement (Kao Vong), Saraburi, Thailand
   quarry 3 = Asia Cement, Saraburi, Thailand
   quarry 4 = Siam Cement (Kang Koi), Saraburi
   quarry 5 = TPI Cement, Saraburi, Thailand
   quarry 6 = Cholpratan Cement (Kang Koi), Phetchaburi, Thailand
   quarry 7 = Siam Cement (Tung Song), Nakhon Si Thammarat, Thailand.

To improve our prediction technique, the author then adopted the modified trend line procedure as suggested by Birch and Pegden [2000]. In this technique, the median of scaled-distance values and the median of predicted peak particle velocity values are first determined. The original lines of their prediction trend pass through the original square root scaled-distance versus the peak particle velocity, while the modified trend lines pass through the calculated "median" location and run parallel to the original trend lines. An example is shown in Figure 4 for the application on the large size quarries using the modified trend line. There are total of 7 quarries which operated in different areas and only quarries 1-4 that their locations are close within the radius of 20 km, others are more than 100 km apart. If all of the data are combined into a single group, the trend line of large quarries is obtained (Line LL in Figure 4).

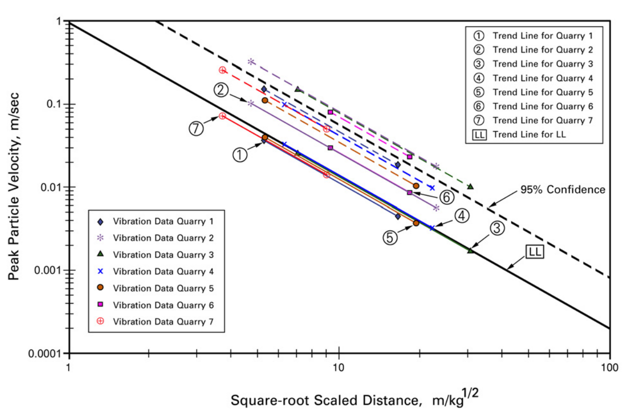

Fig. 4. Square-root scaled distance versus peak particle velocity plots obtained by using the modified trend line. Data are of the same as in Table 2.

DISCUSSION ON SAFE OPERATION AND OPTIMIZATION

An appropriate bench geometry and its blast pattern can be manually designed or written as a packaged program for each quarry site. However, one parameter should be known in the calculation for vibration impact that is the safe distance from the blasting face.

Based on our inspections the recommended value of permitted peak particle velocity, which agree with suggestions from other researchers [Wiss and Nicholls, 1974; Siskind et al., 1980; White and Robinson, 1995] on the level below which no damage occurred, is 0.025 m/s. Recommended values of explosive weights may be subsequently calculated from the modified trend lines.

Table 3 is the design charge weights per delay as determined from graphs in Figure 4. The first column in Table 3 indicates safe distances corresponding to charge weights per delay at various quarries. The safe distance, for example, from blast at quarry 1 (Nakorn Luang Cement) used 326.1 kg of explosive per delay, is 250 m.

Since the value of charge weights per delay for each safe distance is known, engineer can determine the number of drill holes (N) for each blast round. Assuming that V_R is the in-situ rock volume and k is the explosive weights per drill hole.

$$N = \left[\frac{(P.F.)\ (V_R)}{k} \right] \qquad (1)$$

A P.F. value, named the Powder Factor , is defined as the explosive weight used to break a unit volume of rock. The range value of P.F. used AN-FO, providing good fragments and causing less impacts for all 3 rock types, is suggested between 0.4 and 0.6 kg/ m^3.

Next steps in planning of blast design model is to choose the blasting face and the appropriate blast pattern. Topography and geology in each quarry area will determine that the blast operation should be one or two free faces. The blast pattern, however, is complicated and not easy to determine and calculate.

For each blast pattern, the limitation of drill holes (inclined or vertical) can be adjusted or decided. It requires certain set values. Important conditions are the number of rows, bench height and required dense volume are fixed or known.

If V_{req} is the value of its initial required volume and further assuming that an allowable dense volume is %V. The range of volume value is set to be within plus or minus 10 percent of the required volume. Thus the limit number of required drill holes can be calculated from these expressions.

$$N_{min} = \frac{[(P.F.)_{min}]\ [1 - (\%V/100)]\ V_{req}}{k} \qquad (2)$$

and

$$N_{max} = \frac{[(P.F.)_{max}]\ [1 + (\%V/100)]\ V_{req}}{k} \qquad (3)$$

where

k	=	explosive weights per drill hole, kg/hole
N_{min}	=	the minimum number of required drill holes
N_{max}	=	the maximum number of required drill holes
$(P.F.)_{min}$	=	the minimum weight of explosive per unit volume, kg/m^3
$(P.F.)_{max}$	=	the maximum weight of explosive per unit volume, kg/m^3
V_{req}	=	required dense volume which is prior set, m^3
% V	=	percent of volume error (within the range of 10 %), %.

The calculated results, at a fixed row number together with a known bench height, for both values (N_{min} and N_{max}) are essential in pursuing further steps of trial process. Engineer can compare patterns of different design models suggested to match the requirements of rock fragments and to cause less impacts to the environment. These are usually illustrated in the forms of different geometric plan views of blast dimensions, and different ignition delay patterns. The appropriate pattern that one has chosen, should have the value of volume error within the range of 10 percent. At this planning stage, there may be more than one blast pattern that match to the set conditions. It is up to the engineer's decision to choose only one pattern that is the most suitable.

To achieve a high efficient operation is to operate at the minimum cost, the blast optimization is the solution. The first step is to collect data on various bills of expenditures. They are the office and field expenses including wages, drilling and blasting costs, hauling and secondary breakage costs, and an extra cost for bench stabilization and blast damage control.

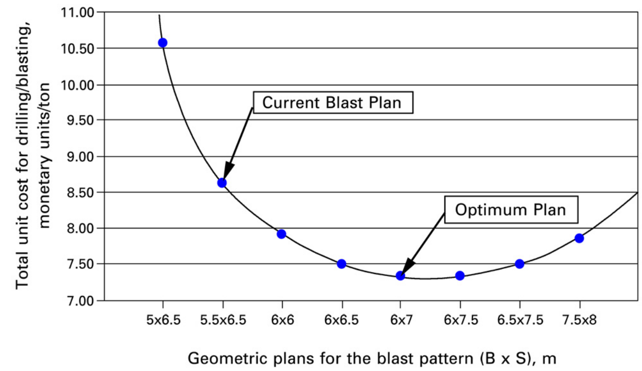

Fig. 5. The trial graph for the drilling and blasting operations.

The second step of optimization procedure assumes blast parameters of one of selected drill pattern are fixed. These parameters are bench height, explosive consumption, dense volume, number of drilled holes, and others. Only the dimensions of its geometric plan view (burden x spacing dimension) can be adjusted. An ideal example for such trial pattern of a typical quarry size, obtained from altering the burden and spacing dimensions, is shown in Figure 5 [Tangchawal 2000 b, 2003]. The unit cost of loading and transporting fragments to the processing plant and other costs are included in the calculation of the total unit cost of operation for one selected blast pattern. Anyhow, the solution of optimum blast plan can have more than one option to choose. The geometric plan view reflects the lowest overall unit cost is not always the best, since the optimum plan is dependent on topography and geology in each local area.

CONCLUSION

There are 3 stages of impact regulations that our research team gives the recommended rules to the Mining Technology Division, Thailand. These stages are for the normal case, the awareness case, and the historic structure case. The regulation rules for the normal case are as presented in this paper. For the awareness case, the rules set that the distance between the community and quarry face is less than 500 m but not less than 150 m. The peak particle velocity limit is 0.012 m/s with any kinds of frequency. A suggested value for this scaled distance is 16 m/kg.$^{1/2}$ The extreme case is the historic structure case and it is set for the threshold limit of antique preservation structure. The distance from the blast source must be more than 150 m. A peak particle velocity must not exceed 0.004 m/s.

An improvement on techniques of quarry blasting would depend on various techniques. The requirements of bench blasting are to be safe and provide less harm to the human and environment. Its blast design has to be economical and easier to adjust or change during the quarry operations. To have greater flexibility and better efficiency in planning processes, engineers should utilize the written program based on the field information and measurement readings in that specific quarry area.

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